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Deforestation and optimal management

Adriana Piazza [a,1], Santanu Roy [b,*]

[a] Universidad Técnica Federico Santa María, Valparaíso, Chile
[b] Southern Methodist University, Dallas, TX, USA

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ABSTRACT

In a general discrete time model of optimal forest management where land may be diverted to alternative use and stocks of standing trees may yield flow benefits, we investigate the economic and ecological conditions under which optimal paths lead to (total) deforestation i.e., complete long term removal of forest cover. We show that if deforestation occurs from some initial state, then it must occur in finite time along *every* optimal path so that zero forest cover is the globally stable optimal steady state. We develop a condition that is both necessary and sufficient for deforestation. Deforestation is less likely if the immediate profitability of timber harvest, the benefits from stocks of standing forests and the timber content of trees are higher. We characterize the minimum forest cover along optimal paths (when deforestation is not optimal). We design a simple linear subsidy on standing forest biomass that can motivate a private owner (who does not take into account the external benefits from standing trees) to conserve forests.

1. Introduction

Deforestation is an important environmental concern. Globally, around 13 million hectares of forests disappeared each year between 2000 and 2010 (Global Forest Resources Assessment, 2010).[2] Social scientists tend to focus on tropical deforestation[3] where weakness of property rights (leading to encroachment and illegal logging) and myopic management practices are some of the key human factors.[4] However, deforestation may occur even when property rights are well defined (and strongly enforced) and forest management is based on a long time horizon. Depending on the intertemporal costs and benefits that a forest manager takes into account, deforestation can be the consequence of an optimal strategy where trees

* Corresponding author. Department of Economics, Southern Methodist University, 3300 Dyer Street, Dallas, TX 75275-0496, USA. Tel.: +1 214 768 2714; fax: +1 214 768 1821.

E-mail addresses: adriana.piazza@usm.cl (A. Piazza), sroy@smu.edu (S. Roy).

[1] Departamento de Matemática, Universidad Técnica Federico Santa María. Avda. España 1680, Casilla 110-V, Valparaíso, Chile. Tel.: +56 22 3037 331; fax: +56 32 2654 563.

[2] According to FAO's Global Forest Resources Assessment 2010 (Global Forest Resources Assessment, 2010) forests currently cover about 4 billion hectares, comprising approximately 31 percent of the earth's land surface.

[3] There is a large literature on tropical deforestation (see, for instance, Angelsen and Kaimowitz, 1999) that focuses on somewhat different economic factors; this literature ignores the age structure of forests.

[4] For an excellent exposition of the literature, see Amacher et al. (2009).

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are cut down without replanting and forest land is diverted to alternative uses over time. This paper attempts to characterize the economic and ecological conditions under which optimal dynamic management leads to deforestation.

Besides timber and shelter, forests provide many environmental services such as biodiversity, water and soil conservation, water supply, climate regulation and carbon sequestration. Reduction in total forest area has led to a decrease in carbon stocks sequestered in the forest biomass by an estimated 0.5 Gt per year over the decade 2000–2010; this has contributed significantly to adverse climate change. Often, there are no markets for such non-timber products and services provided by forests.[5] We highlight the role that such benefits flowing from stocks of standing forests can play in determining whether or not deforestation is optimal, and the implications for design of optimal subsidies to incentivize private owners (that may not take into account these benefits) to conserve forests.

In the existing literature, conditions for optimal extinction and conservation have been characterized for renewable resources whose biological growth depends mainly (if not exclusively) on the size of the remaining population.[6] Forests are however somewhat different from many other renewable resources in that regeneration is largely dependent on the availability of land and on decisions regarding land use. Models of forest management also need to take into account the relatively long rotation, the multi-age structure and the age dependent timber content of trees. In managed forests, trees can always be planted and zero resource stock is not an absorbing state. As a result, the concept of "extinction of a forest" is somewhat different from that for other biological species.[7] In this paper, we focus on (total) deforestation which is said to occur when all available land is diverted to alternative (non-forest) use and the area under forest cover dwindles to zero over time.[8]

Optimal forest harvesting is a problem that dates back to the 19th century. In his seminal paper, Faustmann (1849) proposed an appropriate formula for valuation of an even-aged forest that allows one to determine the optimal rotation length. A wide literature has developed since then in numerous directions that range from more sophisticated growth models to models that allow for non-timber forest products such as tourism and environmental services. Optimal harvesting policies are frequently studied numerically with different types of even-flow constraints, or requiring convergence to a predetermined steady state (Johnson and Scheurman, 1977; Lyon and Sedjo, 1983, 1986).

The optimal timber harvesting problem was reconsidered by Mitra and Wan (1985, 1986) in a discrete time dynamic theoretical framework that allows for more general analytical characterization. In this paper, we consider a variation of this well known model of optimal forest management. It assumes that the timber content per unit of forest area is related only to the age of the trees, so that the forest can be represented as a collection of age classes.[9] The focus of the Mitra–Wan papers (and indeed of much of the subsequent theoretical literature on optimal forest use, see for example Salo and Tahvonen, 2003; Tahvonen, 2004a) is on the dynamics of forest rotation and it is assumed that the total area under forests is fixed over time. In order to study the problem of depletion of forest area, we extend the model to allow for alternative use of land.

Such a model with alternative use was studied analytically by Salo and Tahvonen (2002, 2004). They focus on the existence and uniqueness of the steady state. They show the existence of optimal periodic cycles when the steady state is a pure forestry state (with no alternative use), and the impossibility of such cycles if the steady state is "mixed"; they also analyze the stability of the steady state in the latter case. While their analysis allows for the possibility of an optimal steady state where land is allocated exclusively to alternative use, they do not explicitly study the existence or stability of such a steady state and therefore, their analysis does not shed light on the specific issue of deforestation.

Apart from allowing for alternative use and focusing on deforestation, our model also allows for a flow of benefits from *stocks* of standing forests that may capture environmental externalities that could be taken into account by a social planner, as well as earnings from subsidies (for instance, based on forest area or timber content) and recreational use that add to the profits earned by a private owner.[10] This is in addition to the usual benefits from timber harvests. In the existing literature, a number of papers have studied optimal forest management with stock benefits of various kind; to the best of our knowledge, none of them allow for alternative simultaneous (non-forest) use of land. Bowes and Krutilla (1985, 1989) consider stock benefits from standing forests in an age class forestry model; they extend the Mitra–Wan framework to include a benefit that depends on the standing age class distribution of the forest. They characterize the steady states and the occurrence of periodic cycles.[11] Tahvonen (2004a,b) studies the optimal management of a forest with a somewhat different kind of stock benefit that depend on the positive environmental externality emanating from the forest area devoted to old trees which are never harvested for timber. Apart from the existence of optimal periodic cycles, it is shown that the introduction of such a stock benefit can lead to a continuum of steady states. Our paper extends the broad

[5] The non-market value of a large part of standing forests may exceed the value of timber extracted or even that of converting land to alternative uses (Pearce, 2001).

[6] See, for instance, Clark (1973).

[7] There is a literature on forest use using mining models that focuses on the effect of depletion of old-growth timber stands on prices of timber and allows for the possibility of full depletion. See, among others, Berck (1979), Lyon (1981) and Lyon and Sedjo (1983).

[8] Note that this concept differs from the usual sense of the term "deforestation" as referring to any decline in forest cover.

[9] This assumption may not be applicable to wild forests.

[10] For biological species and other renewable resources whose reproduction depends on existing population size, there is a fairly extensive analysis of optimal conservation and extinction in a framework that allows for stock effects in net benefits from harvesting. See, for instance, Olson and Roy (1996).

[11] Bowes and Krutilla compute examples where deforestation (in their framework, a situation where all land is eventually barren) is avoided only if the stock benefits are taken into account. In these examples, it is assumed that each age class is either fully harvested or left untouched.